The University of Michigan • Office of Research Administration
Ann Arbor, Michigan

July 11, 1966

Office of Grants and Research Contracts
Code SC
Office of Space Sciences and Applications
National Aeronautics and Space Administration
Washington, D. C. 20546

Subject: Letter Progress Report of Work Under Contract No. NASr-54(06) for the Period 1 March 1966 to 31 May 1966

Gentlemen:

This status report covers work during the period from 1 March 1966 to 31 May 1966 under Contract No. NASr-54(06), Man-Machine Performance Measurements. By the end of this period approximately 87% of the budgeted funds for the first and second years have been expended.

Work is continuing on conduct and analysis of experimental studies of human performance characteristics in manual control tasks and the development of techniques for manual control system simulation and for analysis of human performance data.

1. EXPERIMENTAL STUDIES

Operator Performance in Two-State Relay Control Systems

Data analysis is continuing in Experiment 66-1 which investigates an operator's ability to monitor and control an on-going response sequence at two or more levels simultaneously. Our assumption has been borne out that skilled drummers bring to this task experience that produces great proficiency with very little practice. With no external input signals they are able to maintain control of the target and produce an average response rate of approximately 10 responses per second. The subjects were also easily able to maintain control of the external inputs introduced. As an indication of the precision that was required to achieve this control, consider the transition from the positive-going leg to the negative-going leg of the triangular wave having an input frequency of 0.1 cycles per second when the system gain was 100 centimeters per second^2. This transition required a total time difference of 22 milliseconds between the left and right keys and this difference was distributed over roughly five pairs of responses. It was predicted that the nature of the waveform and the frequency of the external input signal would produce variations in the average interresponse times. This prediction was based on the notion that the more stringent the requirement for control at the higher levels, the less attention that could be devoted to maintaining high rates of responding. While the results are in general in the predicted direction, the

magnitude of the differences was smaller than expected. It was hoped that a transient analysis of the subject's response to the external inputs would reveal some fundamental characteristics of the dynamics of higher-level control. It appears that the subject's performance was so good that this kind of analysis may not be fruitful.

Validation Data for Parameter Tracking Models

A second experiment (66-4) has been completed to provide further validating data for the two-parameter tracking model being examined by Mr. Jackson. In this study three subjects performed a compensatory tracking task with controlled element dynamics of $5/s^2$. As before, three random forcing functions were used having cut-off frequencies of 1, 2, and 4 radians per second. It is of interest to determine the values of gain and time delay associated with various phases of learning, and the fraction of the operator's output accounted for by the model.

Human Operator Performance in Pure Time Delay Systems

A new series of studies is being initiated in which operators are required to perform pursuit tracking in a system in which the controlled element dynamics are represented by a pure time-delay element. Time delays of 0.18, 0.36, 0.72, and 1.44 seconds are being employed. In the first phase of these experiments the input signal to be tracked consists of pure sine waves. These data will be used in conjunction with our earlier sine-wave data, to determine the influence of the time delay introduced into the system, over and above that inherent in the subject's performance, on the characteristics of the noise that we have repeatedly found to be present in the operator's output. In the second phase of this series, random input signals having bandwidths of 1, 2, and 4 radians per second will be employed. To our knowledge this range of time delays has not previously been explored in connection with the range of input bandwidths. In addition to measuring average error, these data will be examined with cross-power-spectral analysis techniques to see if pure time delay systems behave in a manner analogous to other comparable dynamic systems. In later phases of this series other dynamic elements in addition to the time delays will be introduced and operator's performance examined.

2. DEVELOPMENT OF DATA ANALYSIS AND SIMULATION TECHNIQUES

Development of Parameter Tracking Models

Analysis of the data from the compensatory tracking study with 5/s dynamics (Experiment 66-3) with the parameter tracking model indicated that values of K, the system gain, and the total time delay associated with the operator and the system were comparable to those obtained by McRuer using correlation techniques. It was also observed that the values of K increased by more than 100 percent on some subjects over the 10 days of practice. τ, over the same practice period, decreased over 50 percent in some subjects. The values of K and τ were also shown to be sensitive to the input-signal bandwidth employed. It was found that the two-parameter model was able to account for 92 to 98 percent of the power in the system

output. Analysis of the second experiment (66-4) employing $5/s^2$ dynamics is underway.

Predictive Display Development and Evaluation

Initial analysis to determine a useful set of non-dimensional parameters describing the characteristics of predictive display systems has been completed. Pilot studies are being initiated to evaluate the extent to which human operator performance varies with these non-dimensional parameters. This pilot work will permit a reconsideration of the appropriate non-dimensional parameters to use before formal experiments are begun.

Effective Manipulator Characteristics on Operator Tracking Performance

Mr. James Herzog has initiated a Ph. D. thesis in the Electrical Engineering Department with support from the subject contract. He is interested in studying and modelling the specific effects of proprioceptive feedback resulting from the force and position cues of the manipulator itself on operator's tracking performance. As a first step, he has designed, and construction is beginning on a tracking control with has programmable variable dynamics.

The control device is a vertical shaft with a horizontal arm support and vertical hand grip. The shaft is instrumented with transducers to provide position, velocity, and acceleration information. Also located on the shaft is a motor capable of producing a torque linearly proportional to its rotor current. An amplidyne driven by an analog computer operational amplifier has been compensated to provide suitable power gain and linearity.

This device will have the capability of supplying torques to the control shaft proportional to displacement of the control stick from its center position. This has properties similar to a physical spring. In the same manner torques proportional to a weighted sum of position, velocity, and acceleration will give the sensation of a spring, mass, damper physical system. The precise nature of the experiments to be performed in the initial phases of this program have not as yet been determined but the primary goal is to manipulate the force and position cues provided by the stick to the operator in such a way that their effects may be isolated.

Simulation Methods

Investigation of the method of constraints, for improving high-speed trajectory computation accuracy has been postponed temporarily. Efforts to avoid problems due to singularities in the constraints have been unsuccessful to date. This investigation will be resumed in the near future.

Application of high-speed computation methods to trajectory optimization, using a direct gradient measurement scheme similar to that of Wingrove, Raby and Crane (NASA TN D-3404) has been made. Due to limitations of the computer equipment available, only very simiplified problems can be solved, at this time. The method is very attractice because of its

simplicity, and it is believed that it will represent a very useful application of very high-speed hybrid computation.

Considerable development work should be done on the direct gradient method, particularly on methods of handling terminal constraints and inequality constraints on the control variable. This will require that a medium size, very high-speed, hybrid computer be available. It is planned to request that funds be allocated to install such a computer in the NASA Space Research Building during the coming fiscal year.

3. RELATED ACTIVITIES

Mr. Eric King-Smith, Senior Lecturer in Electrical Engineering at the University of Sydney, Australia, is serving as a visiting lecturer in the Department of Aerospace Engineering and is contributing to the programs of the subject contract.

Dr. Pew attended the IEEE Annual Symposium on Human Factors in Electronics held in Minneapolis, Minnesota on May 5 and 6. He presented a paper entitled "On the Relation Between Discrete and Continuous Performance." This paper reported data obtained in Experiments 65-1 and 65-2. Dr. Fogarty has had a paper entitled "Computer Generation of Arbitrary Functions" accepted for publication in the journal Simulation.

Personnel

During this reporting period the following personnel have charged time to the subject contract:

	Fraction of Time
L. E. Fogarty	.50
R. M. Howe	.10
R. W. Pew	.40
T. Armstrong	.67
J. Duffendack	.55
L. Fensch	1.00
J. Frait	.50
J. Herzog	.33
E. King-Smith	.20
J. Overmars	.67
R. Rapley	.50
M. Rash	.33
J. Warner	.50

Mr. James Herzog, Mr. Glen Jackson, and Mr. August Burget are participating in the work of the program under a NASA Traineeship, a Ford Foundation Fellowship, and a NASA Fellowship, respectively.

Sincerely yours,

Robert M Howe

Robert M. Howe
Information and Control Engineering
Department of Aerospace Engineering

Richard W. Pew

Richard W. Pew
Human Performance Center
Department of Psychology

Co-Principal Investigators

RWP/mr